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METEOROLOGICAL MEASUREMENTS from THE TIROS SATELLITES

by

W. G. STROUD Aug 1961

GODDARD SPACE FLIGHT CENTER

National Aeronautics and Space Administration

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ABSTRACT

The three TIROS Meteorological Satellites containing television and solar and thermal radiation-detecting instruments have yielded a vast quantity of meteorological and geophysical information on the earth and its atmosphere over the past year and one half. Large numbers of photographs have revealed the unexpected extent of the organization of cloud systems over the earth. Clouds associated with tornados, with mountains and with hurricanes have been brought under observation by the satellites. The radiation detectors have provided maps of the distribution of radiation, both reflected and thermal, over large areas and, in addition to providing knowledge of the distribution of the energy balance have permitted the estimation of cloud heights and temperatures.

The analysis and interpretation of the staggering amount of information that has been acquired is a continuing task.

ACKNOWLEDGEMENT

The preparation of this paper and the scope of the TIROS Project activities have required that the author draw extensively on the work of many of his colleagues and fellow participants in the Meteorological Satellite Program. He is especially indebted to Dr. R. Hanel and his co-workers for the solar and thermal radiation maps and many discussions on the data. The Meteorological Satellite Laboratory staff of the United States Weather Bureau kindly furnished the Hurricane Anna nephanalyses of figures 5 and 6.

The many scientists, engineers, and technicians who prepared the satellites and launched the rockets are an unidentified but very real part of this paper.

INTRODUCTION:

There have been three Television and Infra Red Observations Satellites (TIROS) launched during the past two years for the purpose of making meteorological observations of the earth. Four more are planned. This is a logical point in the program to assess it as an experiment in our studies of the atmosphere and its motions. In addition, the individual satellites have varied in details and in degrees of success; the usual difficulties the experimental physicist encounters, exaggerated by the unusual laboratory in which he is conducting the experiments.

The value of satellites as an observational tool has been long recognized by the geophysicist, and discussed in the literature (1, 2, 3). But the technology of launch vehicles, telemetry and other practical considerations have only recently permitted the realizations of these ideas. The satellite brings to the geophysicist simultaneous observations of large areas of the earth, of regions that he cannot practically put under observation by any other technique, and provides him an entirely new view of the earth -- as a planet.

The method of these experiments is exploratory; as early examples of the exploitation of a new technology they are obviously limited by the lack of knowledge of what parameters are best measured from the satellite and by the experimenter's ability to make the measurement -- his lack of adequate sensors.

Since the clouds are visible manifestations of the thermodynamic processes of the atmosphere and could be photographed by techniques adaptable to the satellite, they have been the first atmospheric phenomenon brought under observation (4) from rockets and satellites. A more refined measurement has been that of the radiation reflected and emitted by the earth and its atmosphere (5). The early rockets, Viking and Aerobee, and satellites, Vanguard II and Explorer VII, measurements, complemented by the continuing development of the launch vehicle technology laid the groundwork for the TIROS system and convinced the experimenters that valid and significant geophysical experimentation could be conducted from a satellite platform.

The TIROS system may be considered as composed of four elements (a) the spacecraft (or satellite) itself, (b) the launch vehicle, (c) the data acquisition sites, and (d) the results and their utilization. This paper addresses itself primarily to the results of the three satellites and the description and analysis of data obtained. Brief descriptions of the spacecraft and the sensory instruments; the launch vehicles, the Thor-Delta rocket; and the data acquisition sites at Wallops Island, Virginia and San Nicholas Island, California are included for logical reasons.

The Spacecraft

The TIROS satellite is a 285 pound pillbox, 42 inches in diameter, 19 inches high, containing a complex of optical, sensory, electronic, and magnetic and mechanical devices for the detection, storage and transmission of the data and for the control of these functions (6). Figure 1 shows the satellite and its major TV components. Figure 2 shows the radiation experiments subsystem. There are four sensory subsystems in the TIROS III satellite, a number which has varied somewhat from TIROS I, which had only the two vidicon camera subsystems. These are the two, wide-angle vidicon cameras, each capable of photographing a 750 by 750 mile area when the satellite is viewing a sun-illuminated area of the earth. The camera characteristics are listed in Table I.

TABLE I

Characteristics of TIROS Cameras

	TIROS I		TIROS II		TIROS III	
	CAMERA 1	2	CAMERA 1	2	CAMERA 1	2
Field of View	104°	12.7°	104°	12.7°	104°	
Lens Speed	8/1.5	8/1.8	8/1.5	8/1.8	8/1.5	
Shutter Speed	1.5 millisec		1.5 millisec		1.5 millisec	
Lines per Frame	500		500		500	
Video Band Width	62.5 kc		62.5 kc		62.5 kc	
Resolution per Raster line, zero nadir angle	1.5-2 mi.	1.2-0.5 mi.	same		1.5-2 mi.	

The five-channel scanning radiometer has been described elsewhere (7); the spectral sensitivities of the five sensors and of the other radiation detectors are listed in Table II.

TABLE II

The Radiation Experiments on the TIROS Satellites

Channel	Purpose	Spectral Sensitivity	Field of View
1	Water Vapor	6.0 - 6.5 microns	5x5 degree
2	Window	8 - 12 "	"
3	Albedo	0.2 - 6.0 "	"
4	Thermal	7.5 - 30 "	"
5	"Vidicon"	0.55 - 0.75 "	"
Wide Field Cone			
a.		Total (black)	35°
b.		Thermal (white)	35°
Hemispheres			
a.		Total (black)	Disc of Earth
b.		Thermal (white)	"

In addition to these sensors there are the solar-cell Ni-CD battery power subsystem and the horizon sensor for attitude determination, the north indicator for picture azimuth indication, and the magnetic orientation control for varying the coupling between the magnetic moment of the satellite and the earth's magnetic field (8).

In all the spacecraft have performed quite well. A summary of the present status of the satellites is given in Table III.

TABLE III

The Launch Vehicle:

The Thor-Delta, a three-stage, liquid-liquid-solid vehicle has been used to successfully launch TIROS II and III. An early version of this rocket, the Thor-Able II, utilizing basically the same propulsive units but different guidance and sequencing, was used for the TIROS I launch. This vehicle has placed the TIROS' into nominal 400 n.m. nearly-circular orbits of 100-minute periods and 48 degrees inclination. Table IV summarizes the orbit characteristics of the three launches.

The statistics for the Thor-Delta launch vehicle are tabulated in Table V. At launch the rocket stands 92 ft. high, is of about 8 ft. diameter and has a lift-off weight of about 112,000 pounds. The performance of the Thor-Delta has been excellent -- five of the six vehicles were successfully fired.

TABLE IV

Orbital Characteristics of the TIROS Satellites

(September 1, 1961)

		TIROS I	TIROS II	TIROS III
Altitude	(Apogee	464.4 s.mi.	454.7	507.1
	(Perigee	432.5 s.mi.	384.6	459.7
Inclination		48.39^{o}	48.53^{o}	47.89^{o}
Period		99.24 min.	98.25 min.	100.4 min.
Launch Vehicle		Thor-Able II	Thor-Delta	Thor-Delta

TABLE V

The Thor-Delta Launch Vehicle

	Stage I	Stage II	Stage III
Fuel	Lox and Kerosene	MDMH and RFNA	Solid
Nominal Thrust (lbs)	150,000	7,500	3,000
Burning Time (sec)	160	109	40
Source	Douglas (Thor)	Aerojet General (AJ10-104)	Allegany Ballistics Lab. (X-248)

The Data Acquisition Stations

For all three TIROS there have been two data acquisition stations, one essentially on each coast of the United States. The TIROS-peculiar ground equipment has been the same throughout the operation, but the type of antenna used to acquire the data has varied.

The basic characteristics of the antenna are that it be of about 30 db gain at 240 mc and be trainable. Despite the fact that 65-foot parabolic "dishes", as well as the General Bronze multiple-helices array, have been used, each of the antennas is capable of automatically tracking the satellites at the data transmission frequency. At present the two stations in use are at Wallops Island, Virginia, the site of the NASA small-rocket range; and, at San Nicholas Island, California, a part of the Pacific Missile Range.

The satellite tracking is done by the Minitrack network of stations; the computed orbital elements are published by the Space Computing Center of NASA.

The operation of the stations is directed by the TIROS Technical Control, a Project function, located at Goddard Space Flight Center. Since TIROS, because it is a spin-stabilized body with fixed camera orientation, can take pictures only when the cameras are directed toward a sun-illuminated area of the earth, this Control Center gathers and analyzes the data on attitude of the satellite, the power balance, the orbital elements and the interesting weather situations in various areas of the earth and computes the programs that the data acquisition sites will use to command the satellite to take pictures over the acceptable areas of the earth. In addition, the Center evaluates the performance of the satellite, institutes emergency procedures for handling unexpected difficulties, either in the satellite or on the ground. In contrast to the picture data, the radiation experiments collect full 100-minute orbits of data and transmit it on command to the ground station without special programming.

On the average, seven orbits of data (about 450 pictures and seven radiation tapes) are obtained each 24 hours. The locations of the two stations is not optimal, -- one acquires five of the seven orbits and there is some overlap -- but have been dictated by practical considerations such as land areas on which to build.

The Utilization of the Data

The data received from the satellite are recorded in several formats at the ground stations. The telemetry data which handles all the "housekeeping" parameters, such as voltages, currents, positions, etc. which measure the performance of the instrumentation, are recorded on strip charts in analog form for immediate analysis. The geophysical data are recorded in two formats, one magnetic tape and two as pictures. Both the picture and radiation data are recorded on high fidelity magnetic tape. These tapes are shipped to GSFC for processing and archival purposes.

For immediate operational use at the station, the picture data are recorded on 35 mm film by means of a photo-kinescope. This film strip is rapidly processed at the station and teams of meteorologists, by projecting the pictures on rough latitude-longitude grids, which are machine-computed right at the stations, are able to prepare nephanalyses of the areas photographed by the satellite. These nephanalyses are prepared in a format for facsimile transmission so that within three to six hours after a satellite pass the "fax" nephanalyses are transmitted to the National Weather Center at Suitland, Maryland, and thence, over the national weather communication circuits to the field users of meteorological data. Within these time intervals these nephanalyses of limited areas of the earth appear at all major Weather Bureau stations throughout the country, on ships at sea, and at many of the U.S. Military installations around the world.

The original film containing the pictures is returned by mail to the Naval Photographic Center in Washington, where it is processed and positive and negative copies are made and distributed to all research users of the data. After gridding, the master film is sent to National Weather records Center in Asheville, North Carolina, from which Center 100-foot strip copies may now be purchased.

The radiation tapes are mailed to GSFC where they are processed in a two-step procedure; first, to a digital magnetic tape format which contains the raw radiation information as a function of time; then, by mating this tape with a similar tape containing the orbital elements and with calibration and attitude data, to a final meteorological radiation tape (again in a binary format) which is the basic method of publication of the data. From this tape, by means of appropriate computer programs and printout equipment, tabulations, grid prints and contour maps on various scales may be obtained. Fifty selected orbits of TIROS II radiation data in the form of 1 in 6 million and 1 in 30 million grid-prints are now in publication as a NASA Technical Report.

The entire processing is an outstanding example of the complexities and the amount of work involved in handling the huge volume of data obtained by the meteorological satellite. References (7b) and (9) give detailed accounts of the radiation data reduction.

RESULTS OF THE TIROS EXPERIMENTS

There have been a number of interesting technological results from the TIROS satellites -- the coupling between the earth's magnetic moment and that of the satellite (8), the long term operation of bearings in the hard vacuum of space, etc. (10); but, this paper will be concerned with the geophysical results. The results may be grouped into three classes: (a) the operational use of the picture data in meteorology; (b) the research use of the picture data in meteorology and geophysics; and, (c) the research use of the radiation data. Only limited examples of each group will be possible in this paper. Much has been published or is in publication (7, 10, 11, 12) and if the quantity of data being collected is any measure, much more will be published.

An example of one of the operational nephanalyses produced by the TIROS satellite is shown in Figure 3.

The pictures taken by the satellite were projected one by one on latitude-longitude grids of the areas photographed after identification of the cloud types and characteristics, standard symbols were marked on the map and the boundaries of the cloud systems and the satellite coverage noted. The area from West Africa to Western United States, north to Canada and south to Colombia has been brought under observation. The following figure (4) is an example of one of the roughly 200 photographs used to produce the nephanalyses of Figure 3.

A good example of the value of the nephanalyses is shown in Figure 5 wherein the TIROS III was tracking Hurricane Anna. And, in Figure 6, one of the photographs used in the July 21st nephanalysis is shown.

Whereas the nephanalyses are largely produced at the data acquisition sites, the research use of the pictures for meteorology and geophsics is done in the more leisurely atmosphere of the laboratory. Here the study of special events and phenomena such as the Benard-cell-like cloud forms over the Pacific, the cloud structure of an occluded cyclone, mountain clouds, the intensity, size and distribution of northern and southern hemisphere cyclones, the distribution of mountain snow, ice formations and flow in the St. Lawrence estuary, and the variations in coloration of the land surface, the glint from the sea -- may all be conducted (13). Figures 7, 8, 9 and 10 are examples of these observations.

The reflected and emitted electromagnetic radiation measurements which are briefly designated as radiation measurements in the following text seem to be the most significant data being acquired by the satellites. The reduction of the data to a format from which they can be readily assimilated and studied has been quite difficult (7b), but is now becoming somewhat routine. At present, only a fifty-orbit sample of the TIROS II data have been processed to grid-prints and printouts that permit analysis and interpretation.

Despite the difficulty of precise, absolute radiometric measurements, even in the laboratory, the TIROS II and III experiments have shown that significant measurements can be made from the satellite. The data from Orbit 88, taken on November 29, 1960 over the Atlantic Ocean and North

Africa are shown in Figures 12, 13, 14, 15 and 16 with the surface weather chart nephanalysis shown in Figure 11. Only the data from the five-channel scanning radiometer are given in these figures which are described briefly in the legend to each.

Some general comments about the group are pertinent. The values of radiation received at the satellite from the area on the map are given in watts per square meter. The weather system at the time of the satellite pass over the area was obtained by conventional techniques since TIROS II cloud photographs of the area were not available (Figure 11). A frontal system extended from Ireland over the ocean toward the southwest. Over large areas of the ocean, French West Africa and Algeria, no cloud data (NCD) were available.

CONCLUSIONS

There are available from the TIROS meteorological satellites a tremendous range of new geophysical data. The major problem confronting the experimenters involved is the task of adequately sifting through the vast quantities of photographs and maps to make sense of them; to find the patterns and the continuity which permit one to deduce and to relate the new information to the present theories and concepts.

It is a sizeable task, but probably the only practical means by which the atmosphere as a global phenomena will be brought within man's understanding.

TABLE III

Performance of the TIROS Satellites

September 1, 1961

	TIROS I	TIROS II	TIROS III
Launched	April 1, 1960	November 23, 1960	July 12, 1961
Days of Data Transmission	78*	Still Transmitting	Still Transmitting
Approx. No. of Pictures Transmitted	23,000	35,650	12,000
Orbits of Radiation Data Obtained	**	1,601***	367
Major Failures:	1. Narrow angle camera out between orbits Nos. 22 & 572.	1. Wide angle lens coated by rocket exhaust, pictures poor.	1. One camera shutter hung up.
	2. Relay failure destroyed battery power system.	2. Decay of interference filters on two scan radiometers after several months.	2. Decay of interference filters on two scan channels of radiometer.

*Beacons still transmit when in sunlight.

**The radiation experiments were not included in TIROS I.

***Five channel radiometer motor stopped 4/27/61. Balance of subsystem still operating.

FIGURES AND LEGENDS

FIGURE 1: The TIROS Satellite and Its Major Components.

The base plate with the TV camera lenses, projecting downward among the antennas and topped by the "hat", covered with solar cells, is readily identified. In the lower left is a vidicon camera with lens - in the front center is the video tape record for storage of the camera pictures. In the left rear the five bright discs identify the five-channel scan radiometer. The other components are beacons, control circuits, diplexer and switches all mounted on the base plate.

FIGURE 2: The Radiation Subsystem of the TIROS Satellite.

The 100 minute tape recorder is shown in the left rear with the DC/DC converter deck in front. Front center is the electronics deck containing the seven-channel telemetry and the tuning-fork clock for keeping time in the satellite. The 235 mc transmitter is right front. All components and decks are mounted in the pressurized can.

FIGURE 3: The TIROS III Nephanalyses for July 18, 1961 Over the Atlantic-from Seven Orbits.

The standard meteorological cloud symbols have been used and are in the legend in the lower left. The boundaries of satellite coverage are shown by heavy lines, the cloud boundaries are lighter. A vortex was visible and is indicated off the West coast of Africa. The eastern United States iscovered with a heavy overcast. In many areas, such as over the Yucatan peninsula, tongues of clouds and clear areas indicate a circulation pattern. Broken cloud patterns cover the major Caribbean islands, while the water areas are clear. Much of the area is not under the observation afforded by the satellite.

FIGURE 4: An Example of Cloud Photographs Used to Produce Nephanalyses Like Figure 3.

Shown is the West Coast of Africa between Cape Blanco at the top right and Dakar at the bottom center. The area out over the water is covered with broken, cumuliform clouds.

Figures and Legends (Continued)

FIGURE 5: Successive Nephanalyses from TIROS III of the Caribbean Area and Hurricane Anna, July 20 through 23, 1961.

The upper left frame shows the vortex off Venezuela and the photograph that was used to identify it and the cloud cover of the surrounding area. In the upper right frame the hurricane is more centered in the satellite pass and the vortex has moved about seven degrees due west in one day. The lower frames, taken July 22nd and July 23rd indicate the hurricane moving toward Honduras and dissipating over the land. The hurricane was not noticed on the nephanalyses of Figure 3 taken on July 18, two days before it appeared on Orbit 117 photographs.

FIGURE 6: Hurricane Anna on July 21, 1961:

The hurricane is shown off the coasts of Venezuela and Colombia, which run across the picture from lower right to upper left. The Lake Maracaibo in Venezuela may be discerned in the lower center of the photograph. The eye of the hurricane is not visible at this time, but the circulation pattern is.

FIGURE 7: TIROS III Photograph of Florida.

Well-developed convective cumulus clouds covering the land areas may be identified by their brightness. A squall line running east-west lies out over the Gulf of Mexico to the west of Tampa, Florida.

FIGURE 8: The Iberian Peninsula and the Straits of Gibralter, July 15, 1961.

A bright cloud bank lies over the Pyrenees Mountains. At the top of the picture may be seen the circular pattern of a cyclonic storm in the North Atlantic.

FIGURE 9: The Sahara Desert of North Africa and the Gulf of Sidra, Off Libya.

This is a dramatic view of the desert coloration so often observed. The Oasis of Kufra, a plateau area of Libya, is the dark patch on the right center of the picture.

FIGURE 10: A TIROS III-Located Tropical Storm Named Liza.

This example of a storm from an area of no weather reports lies west of Lower California. TIROS III located the center on July 19, 1961 at 25°N and 123°W.

Figures and Legends (Continued):

FIGURE 11: A Nephanalysis from Surface Weather Data on TIROS II Orbit 88, Over the Atlantic Ocean and North Africa.

The sub-satellite path is the heavy dashed line through the center of the figure. The boundaries of coverage by the five-channel radiometer are defined by the heavy shaded areas. The satellite made measurements within this entire area. No cloud data (NCD) were available over large areas (see text).

FIGURE 12: TIROS II Scanning Radiometer Water Vapor Channel at 6.0 - 6.5 Microns, Orbit 88.

The narrow spectral band and the low energies available make the precision of the absolute values of radiation poorer than on other channels. The corresponding blackbody temperatures of the "hot" region over Spanish West Africa are 253°K. The physical meaning of this region, which is not apparent on other channels, is not clear.

FIGURE 13: TIROS II Scanning Radiometer Atmospheric Window Channel at 8 to 12 Microns, Orbit 88.

This channel has yielded the most accurate and readily-interpreted results. The low values of radiation, $\bar{W}$ = 13 watts per square meter, equivalent to a blackbody temperature of 223°K, are identified with the high cloudy area associated with the front and storm center out over the Atlantic - to the left. Temperatures of 240°K ($\bar{W}$ = 20) were observed quite often - the maximum temperature was 293°K over the desert. Notice the cold region (clouds ??) over the Atlas Mountains. It is possible to estimate the heights of the clouds from these data!

FIGURE 14: TIROS II Scanning Radiometer, Albedo Channel at 0.2 to 6.0 Microns, Orbit 88.

This reflected solar energy map appears very often like the reverse of the window or the thermal channel. High cloudiness is bright, so clouds will reflect less solar energy, unless the surface albedo is high, as it is over the desert. Thus, the maps by themselves may lead to erroneous conclusions. This channel is sensitive to solar elevation angle, so computation of the values of albedo for the various surfaces is difficult. The clear bright area over the Sahara (on right) has an albedo of 28 percent, whereas, the Moroccan area has a low albedo of 6 percent, suggesting some vegetation.

Figures and Legends (Continued):

FIGURE 15: TIROS II Scanning Radiometer Thermal Channel at 8 to 30 Microns, Orbit 88.

The thermal map is quite similar to that from the window (Figure 13). The maximum temperatures were about 15°C lower than those of Channel 2, suggesting that the radiation is emanating from higher levels of the atmosphere. The area to the west of Iberia, which was bright (42 percent albedo) in the albedo channel, is only slightly cooler than the surrounding regions, indicating a low cloud deck.

FIGURE 16: TIROS II Scanning Radiometer Narrow-Band Visible Channel at 0.55 to 0.75 Microns, Orbit 88.

These data are of poorer quality with no strongly identifiable pattern that can be associated with the other channels. It is probably much more susceptible to solar elevation angle corrections.

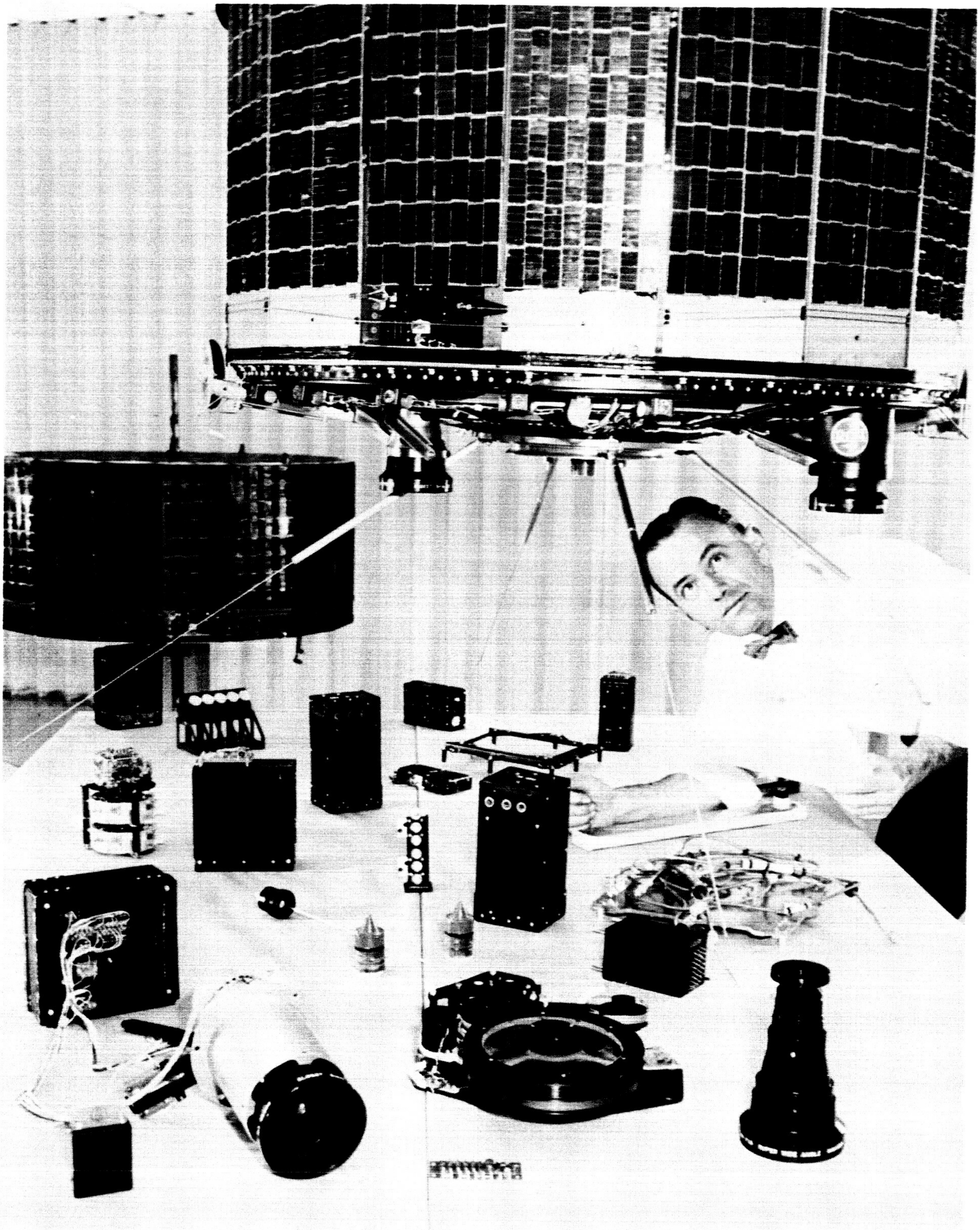


FIGURE 1: The TIROS Satellite and Its Major Components.

FIGURE 2: The Radiation Subsystem of the TIROS Satellite.

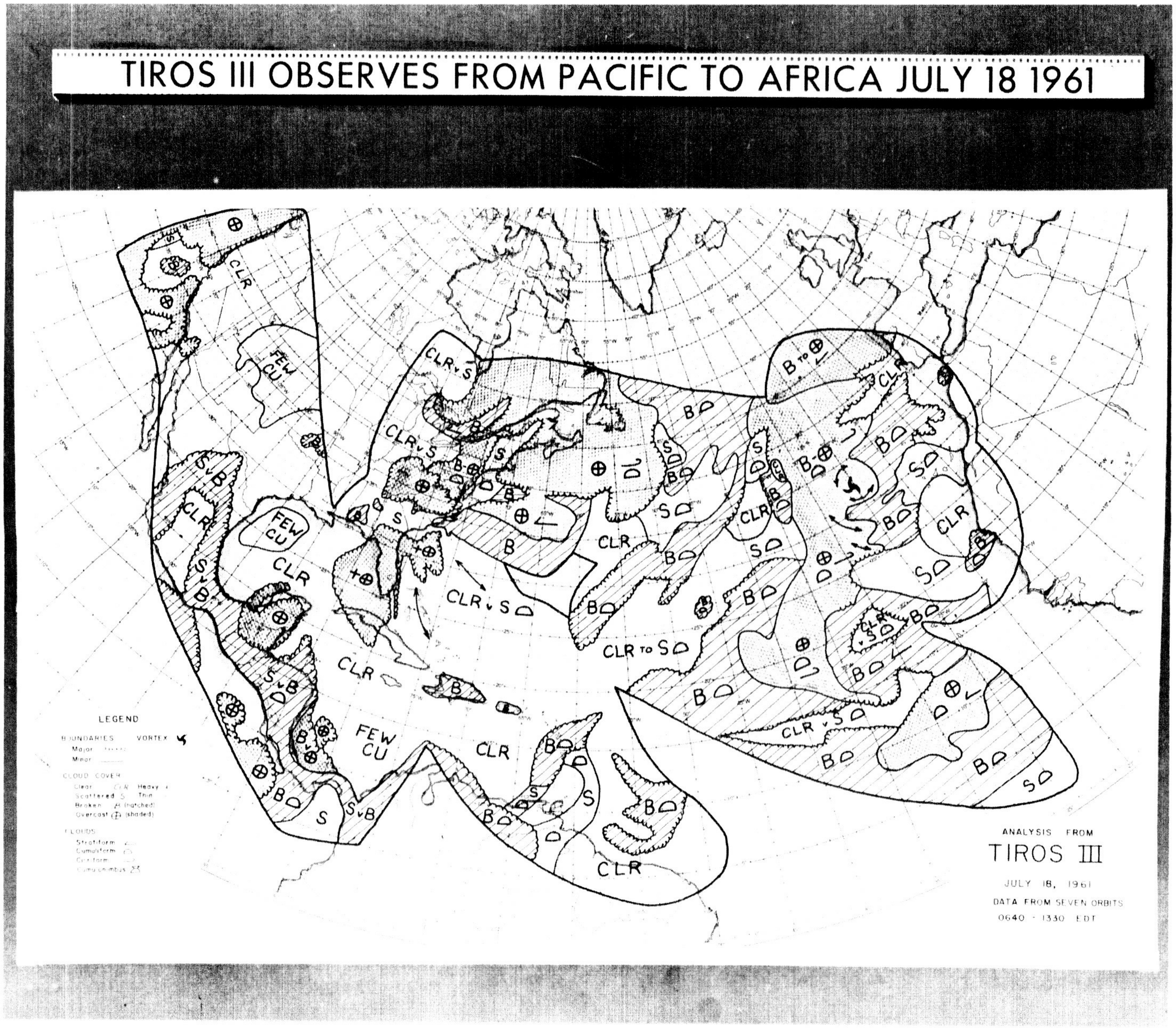


FIGURE 3: The TIROS III Nephanalyses for July 18, 1961 Over the Atlantic-from Seven Orbits.

FIGURE 4: An Example of Cloud Photographs Used to Produce Nephanalyses Like Figure 3.

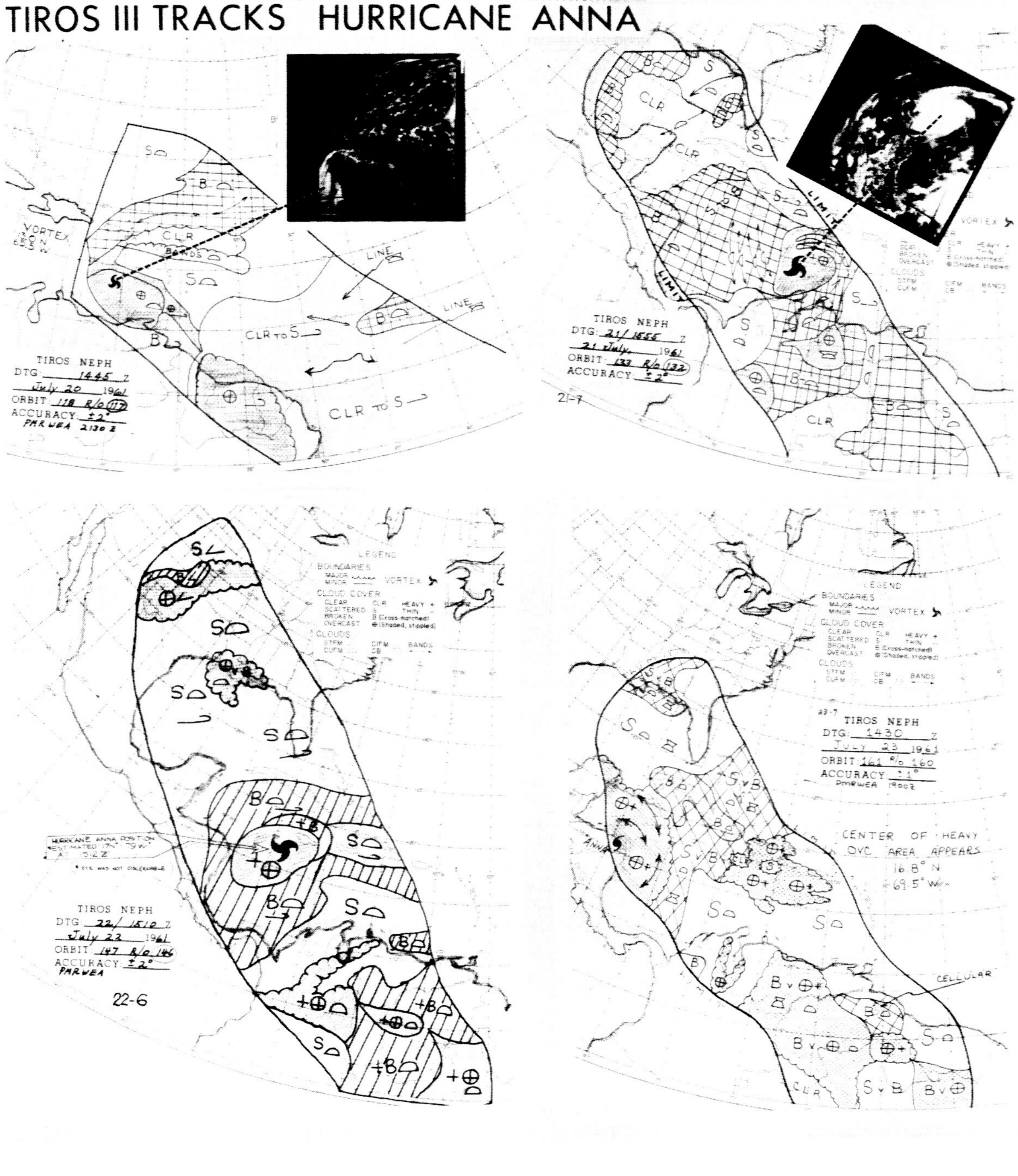


FIGURE 5: Successive Nephanalyses from TIROS III of the Caribbean Area and Hurricane Anna, July 20 through 23, 1961.

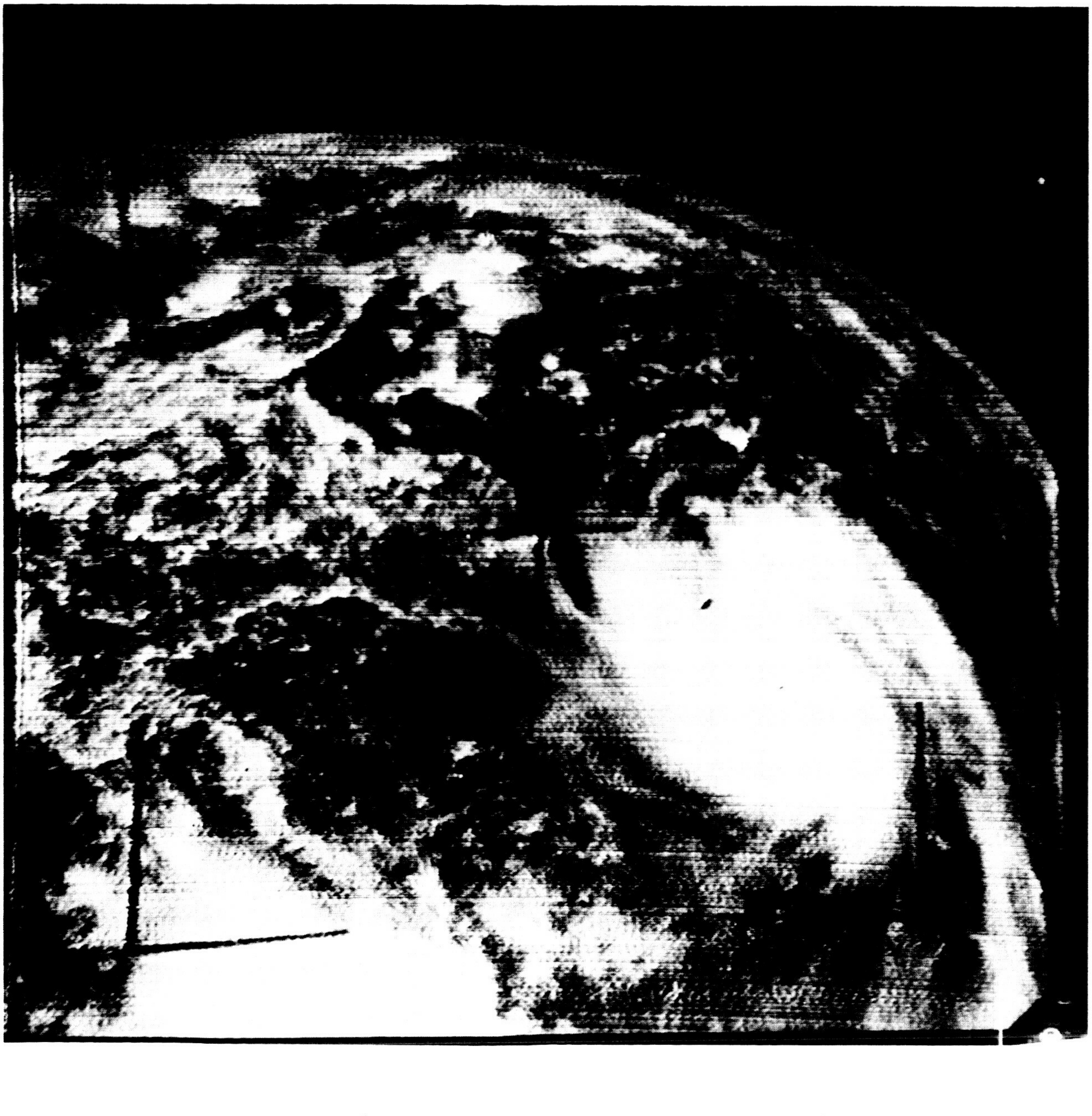


FIGURE 6: Hurricane Anna on July 21, 1961

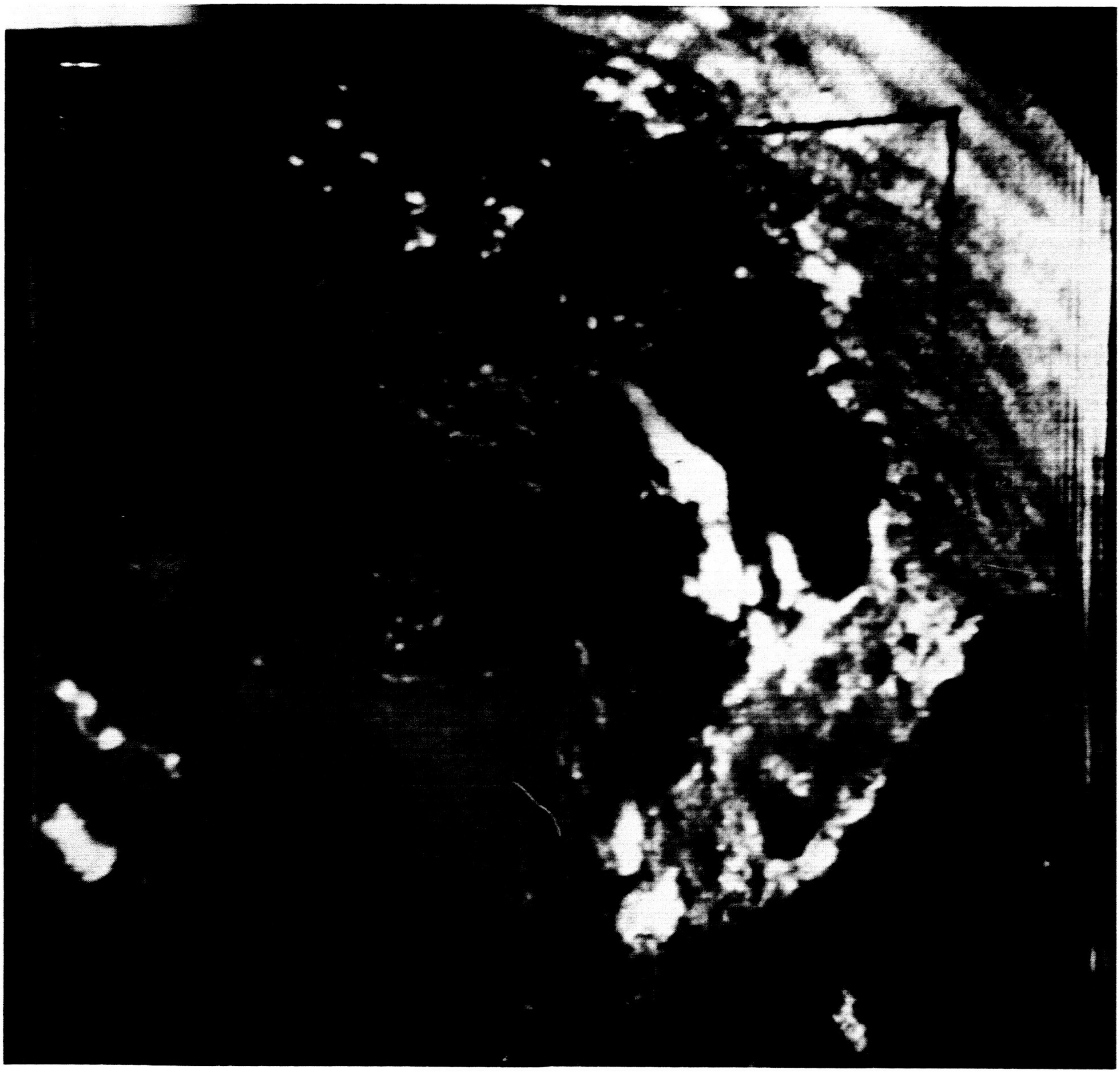


FIGURE 7: TIROS III Photograph of Florida.

FIGURE 8: The Iberian Peninsula and the Straits of Gibralter, July 15, 1961.

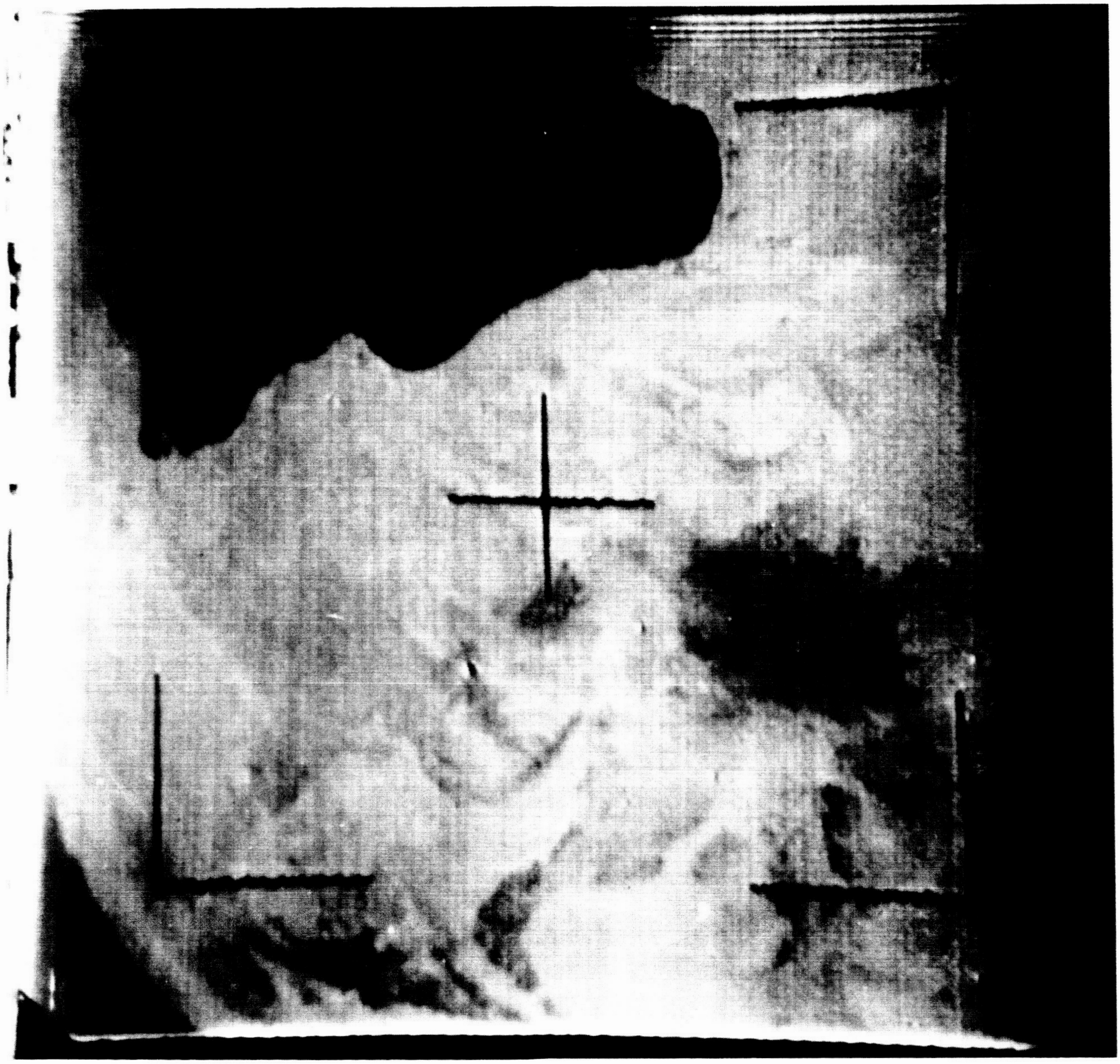


FIGURE 9: The Sahara Desert of North Africa and the Gulf of Sidra, Off Libya.

FIGURE 10: A TIROS III-Located Tropical Storm Named Liza.

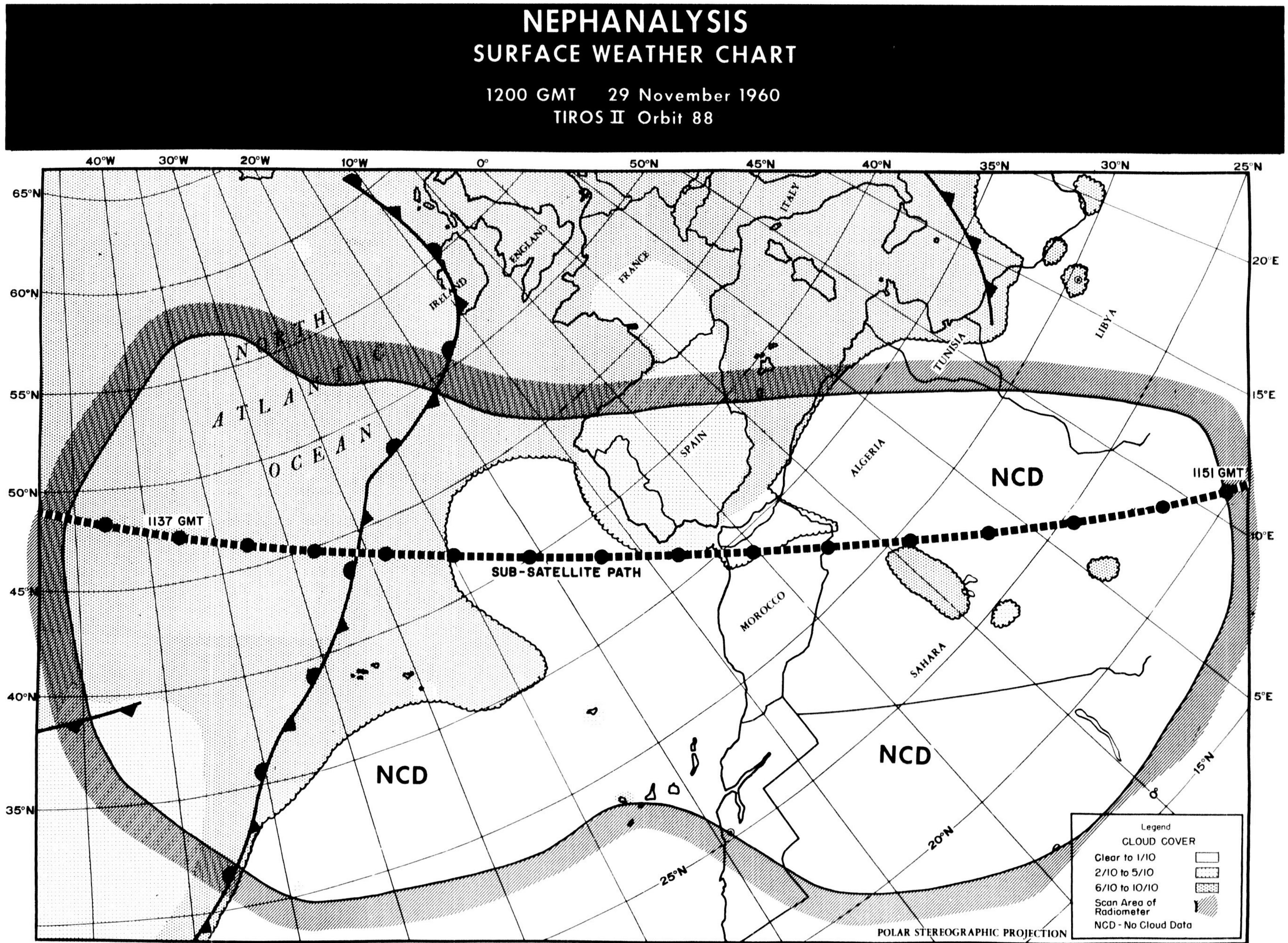


FIGURE 11: A Nephanalysis from Surface Weather Data on TIROS II Orbit 88, Over the Atlantic Ocean and North Africa.

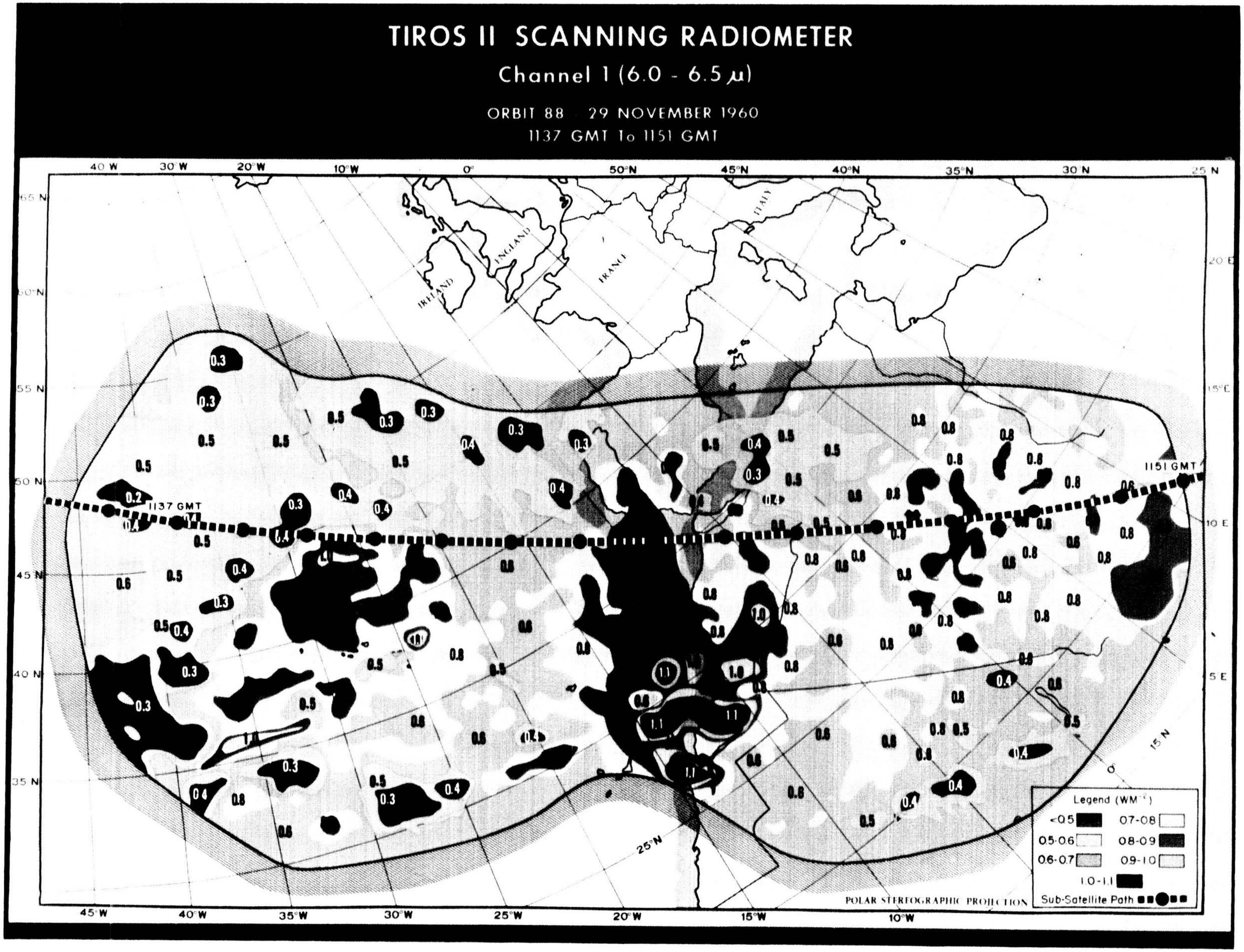


FIGURE 12: TIROS II Scanning Radiometer Water Vapor Channel at 6.0 - 6.5 Microns, Orbit 88.

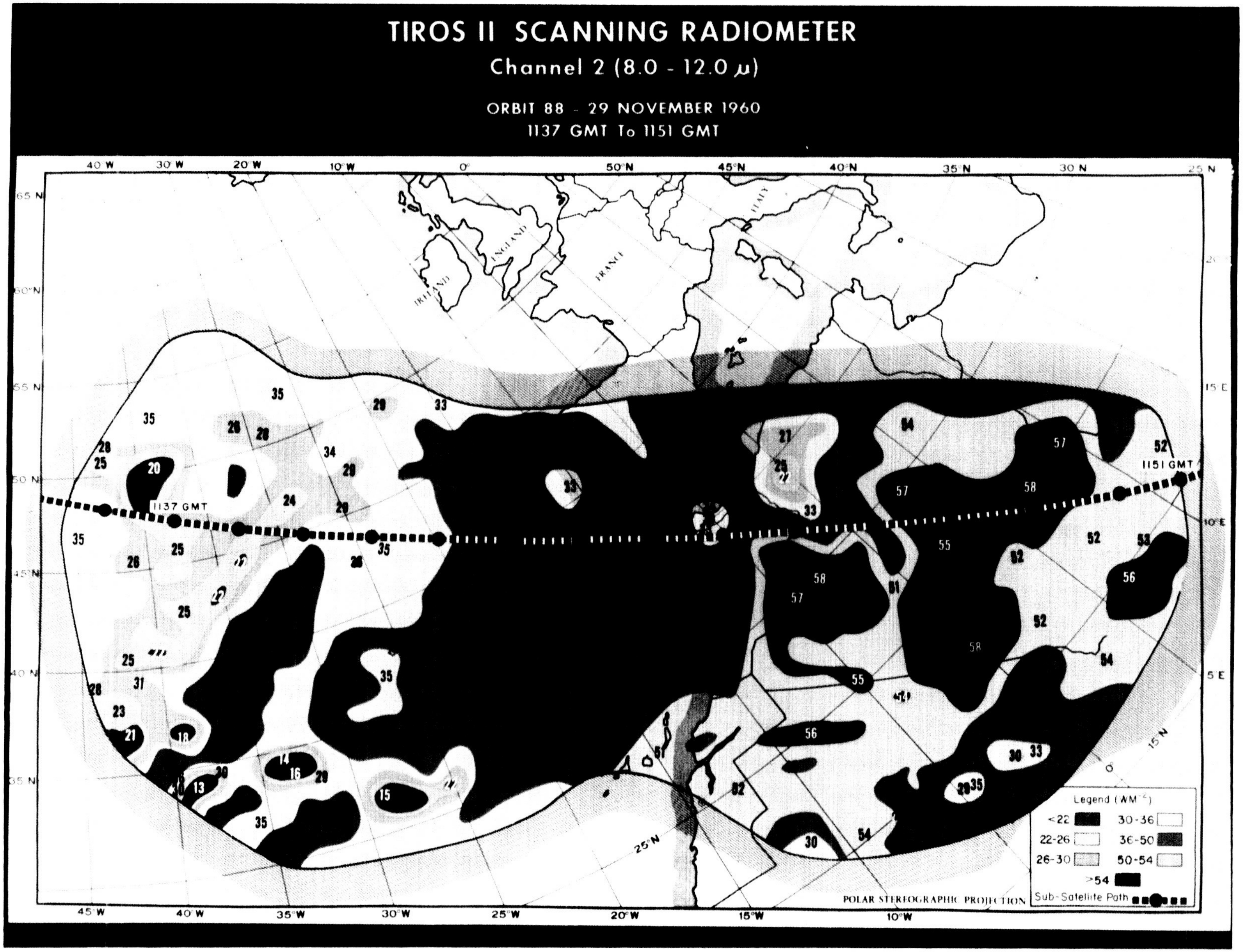


FIGURE 13: TIROS II Scanning Radiometer Atmospheric Window Channel at 8 to 12 Microns, Orbit 88.

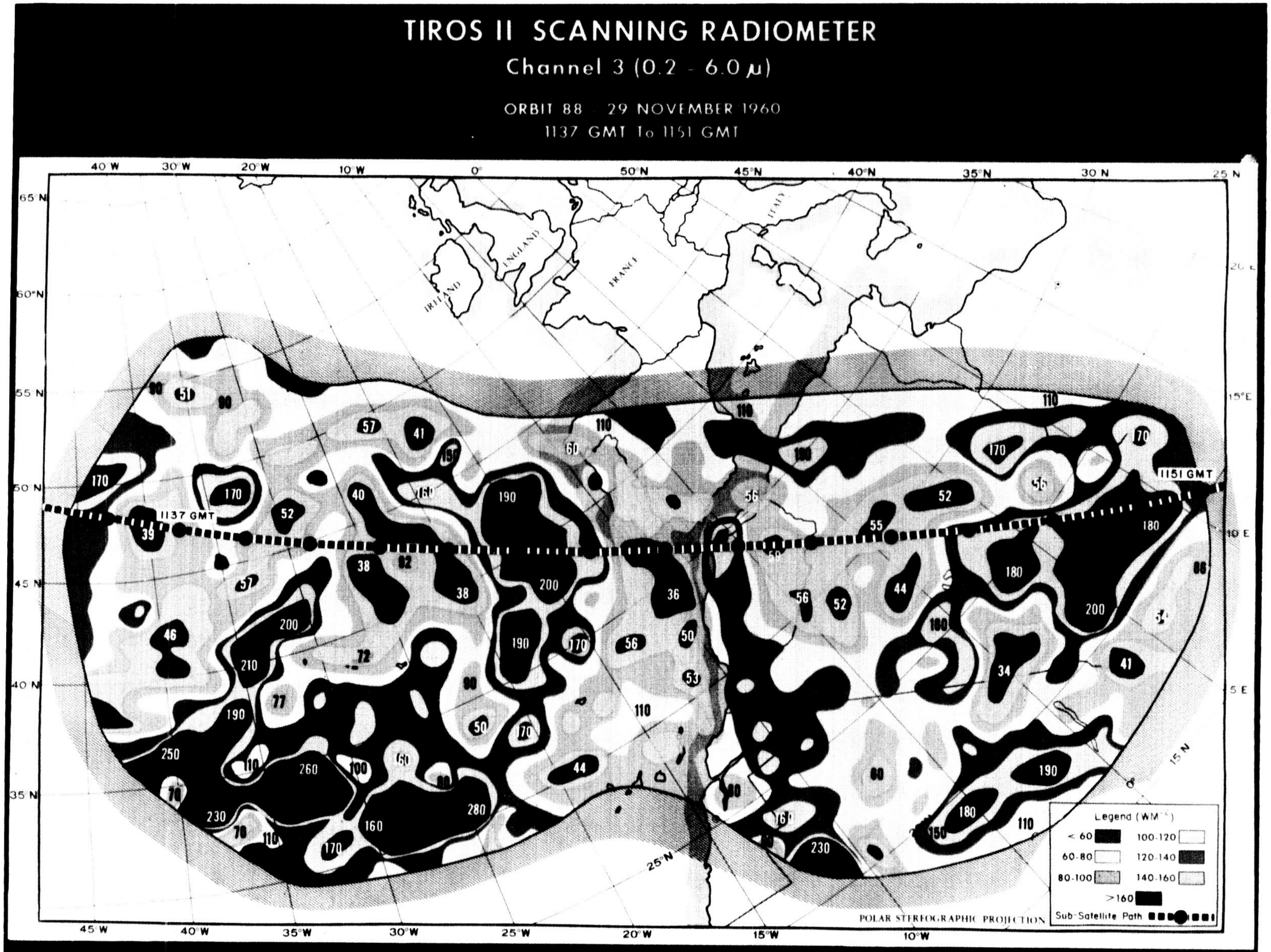


FIGURE 14: TIROS II Scanning Radiometer, Albedo Channel at 0.2 to 6.0 Microns, Orbit 88.

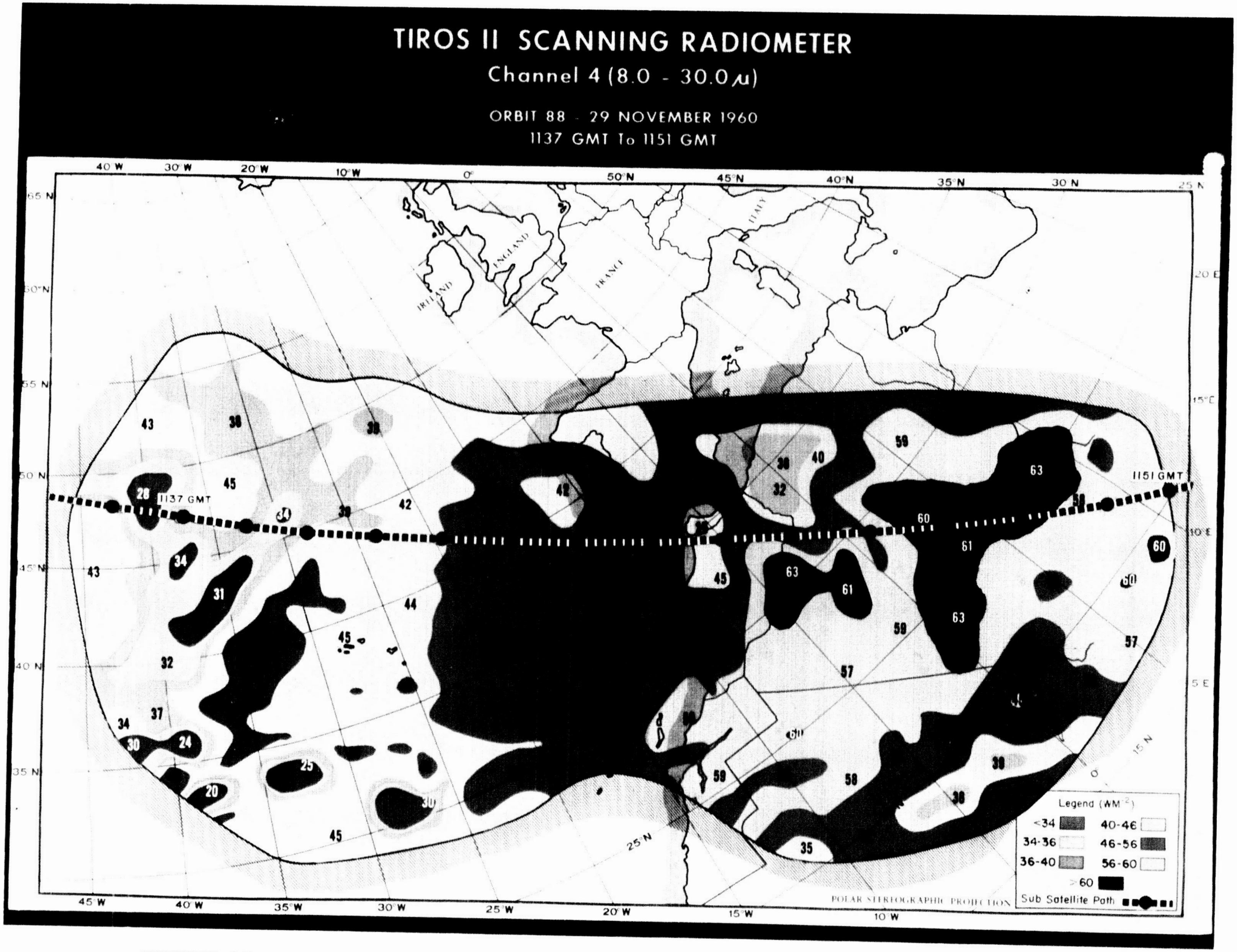
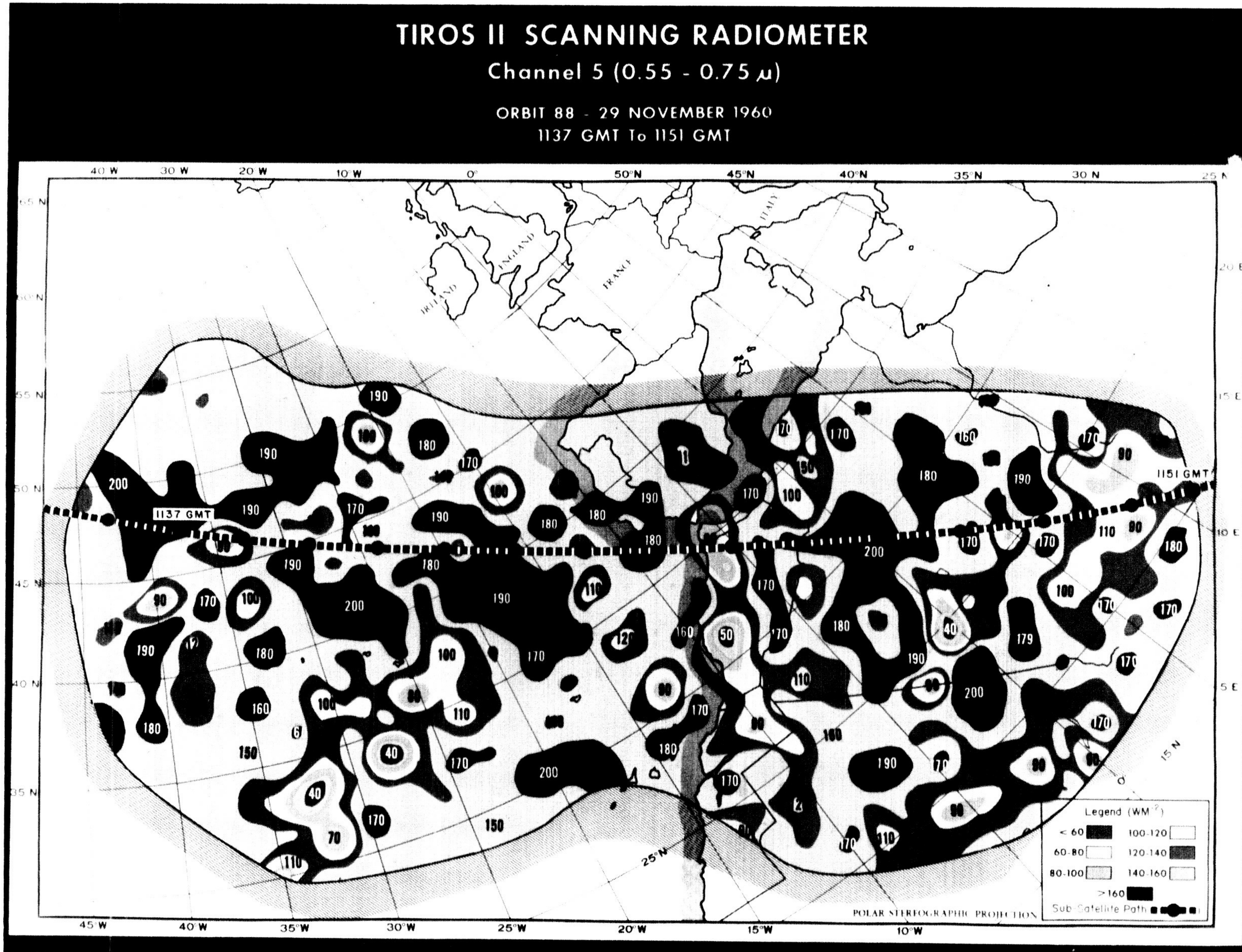


FIGURE 15: TIROS II Scanning Radiometer Thermal Channel at 8 to 30 Microns, Orbit 88.



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REFERENCES

1. Greenfield, S.M. and Kellogg, W.W. "Inquiry into the Feasibility of Weather Reconnaissance from a Satellite Vehicle", Rand Corporation Report R-365, August 1960.

2. Wexler, H., "Observing the Weather from a Satellite Vehicle", Journal of the British Interplanetary Society, 13(5):269-276, September 1954.

3. Stroud, W.G. and Nordberg, W., "Meteorological Measurements from a Satellite Vehicle", Chap. 13 Scientific Uses of Earth Satellites, James A. Van Allen, Editor, Ann Arbor, U. of Mich. Press 1956.

4. a) Hubert, L.F. and Berg, O., "A Rocket Portrait of a Tropical Storm", Monthly Review 83(6): 119-124, June 1955.

   b) Hanel, R.A., Licht, J., Nordberg, W., Stampfl, R.A., and Stroud, W.G., "The Satellite Vanguard II: Cloud Cover Experiment", IRE Transactions, Vol. MIL-4, Nos. 2 and 3, April - June 1960.

5. Suomi, V.E., Parent, R.J., and Swift, W.B., "The Thermal Radiation Balance Experiment on Board Explorer VII, N-85910, U. of Wisc. 1960.

6. a) Sternberg, S. and Stroud, W.G., "TIROS I Meteorological Satellite", Astronautics 5(6): 32-34, 84-86, June 1960.

   b) TIROS I Meteorological Satellite System, Final Operational Report, Astro-Electronics Division of RCA, Princeton, N.J., October 1960.

7. a) Hanel, R.A., and Stroud, W.G., "Infrared Imaging from Satellites", Journal SMPTE 69:25-26, January 1960.

   b) Bandeen, W.R., Hanel, R.A., Licht, J., Stampfl, R.A. and Stroud, W.G., "Infrared and Reflection Solar Radiation Measurements from the TIROS II Meteorological Satellite". In publication: Journal of Geophysical Research, October 1961.

8. Bandeen, W.R., and Manger, W.P. ="Angular Motion of the Spin Axis of the TIROS I Meteorological Satellite Due to Magnetic and Gravitational Torque", Journal of Geophysical Research, Vol. 65, No. 9, 2992-2995, September, 1960.

9. Staff, Aeronomy & Meteorology Division, Goddard Space Flight Center, and Meteorological Satellite Laboratory of U. S. Weather Bureau: (a) TIROS II Radiation Data Users' Manual, and (b) TIROS II Radiation Data Catalogue. In publication as NASA Technical Memoranda, September 1961.

10. Tepper, M., "TIROS Program Results", Astronautics, p. 61, May 1961.

References (Continued):

11. Staff, Aeronomy & Meteorology Division, Goddard Space Flight Center, and Meteorological Satellite Laboratory of U.S. Weather Bureau: Final Report of TIROS I Meteorological Satellite System, NASA Technical Report, In publication, September 1961.

12. Hanel, R.A., and Stroud, W. G., "The TIROS II Radiation Experiment"- In publication, Tellus, November 1961.

13. a)Wark, D,.Q., and Popham, R.W., "TIROS I Observations of the Ice in the Gulf of St. Lawrence", Monthly Weather Review 88, 182 (1960).

    b)Winston, J.S. and Tourville, L., "Cloud Structure of an Occluded Cyclone Over the Gulf of Alaska, as viewed by TIROS I", Bulletin American Meteorological Society 42, 151 (1961).

    c)Hubert, L.F., "A Subtropical, Convergence Line of the South Pacific", Journal of Geophysical Research 66, 797 (1961).